Research Tracker 6 accelerometer calibration and validation in comparison to GENEActiv, ActiGraph, and gas analysis in young adults

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Original citation & hyperlink:
Eyre, E, Tallis, J, Wilson, S, Wilde, L, Akhurst, L, de Souza Junior Wanderley, R & Duncan, M 2019, 'Research Tracker 6 accelerometer calibration and validation in comparison to GENEActiv, ActiGraph, and gas analysis in young adults' Journal for the Measurement of Physical Behavior, vol. 2, pp. 176-187
https://dx.doi.org/10.1123/jmpb.2018-0028

DOI 10.1123/jmpb.2018-0028
ISSN 2575-6605
ESSN 2575-6613

Publisher: Human Kinetics

ABSTRACT

Background: The ability to objectively assess physical activity and inactivity in free living individuals is important in understanding activity patterns and the dose response relationship with health. Currently, a large number of research tools exist, but little evidence has examined the validity/utility of the Research Tracker 6 (RT6) monitor. Questions remain in regard to the best placements, positions and cut points in young adults to determine activity intensity, across a range of activities. This study sought to address this gap in young adults. The study aims were: 1) To examine criterion validity of RT6 in comparison to breath by breath gas analysis; 2) Convergent validity of RT6 in comparison to ActiGraph and GENEActiv; 3) Development of RT6 tri-axial vector magnitude cut points to classify physical activity at different intensities (i.e. for sedentary, moderate and vigorous); 4) To compare the generated cut-points of the RT6 in comparison to other tools.

Methods: Following ethics approval and informed consent, 31 young adults (Age =22±3years: BMI=23±3kg/m^2) undertook 5 modes of physical activity/sedentary behaviours whilst wearing three different accelerometers at hip and wrist locations (ActiGraph GT9X Link, GENEActiv, Research Tracker 6). Expired gas was sampled during the 5 activities (MetaMax 3B). Correlational analysis assessed the relationship between accelerometer devices and METs/VO_2. Receiver Operating Characteristic Curves analysis were used to calculate area under the curve and define cut points for physical activity intensities.

Results: Research Tracker 6 demonstrated criterion and convergent validity (r range=0.662 to 0.966, *P*<0.05). The Research Tracker 6 generally performed good to excellent across activity intensities and monitor position (Sedentary (AUC=0.862, 0.911), moderate (AUC=0.849, 0.830) vigorous (AUC=0.872, 0.877) for non-dominant and dominant position respectively. Cut points were derived across activity intensities for non-dominant and dominant worn Research Tracker 6 devices. Comparison of the RT6 derived cut points identified appropriate agreement with comparative tools but yields the strongest agreement with the ActiGraph monitor at the hip location during sedentary, light and moderate activity.

Conclusion: The Research Tracker 6 performed similar to the, ActiGraph and GENEActiv and is capable of classifying the intensity of physical activity in young adults. As such this may offer a more useable tool for understanding current physical activity levels and in intervention studies to monitor and track changes without the excessive need for downloading and making complex analysis, especially given the option to view energy expenditure data whilst wearing it. The Research Tracker 6 should be placed on the dominant hip when determining activities that sedentary, moderate intensity or vigorous.

Physical Activity, Measurement, METs, Calorimetry, Cut-points

INTRODUCTION

Physical activity is a modifiable risk factor for disease and quality of life (WHO, 2010). Current physical activity guidelines suggests adults should engage in at least 150 minutes of moderate intensity activity in bouts of 10 minutes or more per week (CMO, 2010). Thus, the ability to estimate physical activity and inactivity in free living individuals is important in public health research for several reasons 1) understanding the prevalence of physical activity, 2) determining the dose-response of physical activity with health outcomes and 3) examining intervention outcomes. A large number of tools exist to assess physical activity, yet these differ in their calculations and wear location. Of further interest is the translation of this information beyond a research environment into the practical field to be used by clinicians and practitioners.

For these reasons, recent focus has been placed on the validity of estimating activity intensities in children (Chinapaw et al., 2010; De Vries et al., 2009; Lubans et al., 2011) older adults (Garatachea et al., 2010) and to a lesser extent, young adults (Watson et al., 2014). Young adults are a group of interest as globally, sharp declines in physical activity patterns and increasing sedentary patterns are seen from the transition from adolescence into adulthood (Office of Disease Prevention and Health Promotion, 2010; McVeigh et al., 2016;Telama et al., 2015). Additionally, the type, intensity and duration of the activities they engage in are likely to differ from those of children and older adults. The need for accurate and affordable tools to assess physical activity in these populations is therefore important in understanding physical activity, inactivity and associated health outcomes.

Accelerometers are a widely used tool to determine physical activity levels in public health research. Many accelerometer-based tools exist, providing an activity 'count' as their output. These counts are applied to thresholds which determine durations and frequencies of activities at specific intensities. Specifically, the ActiGraph, Actical and Research Tracker 3 (RT3), which is an older model of the Research Tracker 6 (RT6) are the most commonly used accelerometers in physical activity research. Much research has examined the validity and reliability of different ActiGraph monitors, suggesting it provides a valid and accurate estimate of physical activity intensities (John, Tylo & Basset, 2010; Plasqui & Westerterp, 2007). A newer tool, the GENEActiv has demonstrated excellent reliability and validity against breath-by-breath VO_2, derived from indirect calorimetry, ActiGraph and RT3 counts in older adults across different intensities (Esliger et al., 2011). Additionally, the GENEActiv's ability to determine sedentary behaviour in adults (18-55 years) has been reported (Pavey et al., 2016). Yet, the RT3 is not as extensively researched as other commercial tools (e.g. ActiGraph, Actical) and even less is known about its more recent model, the RT6. Measurement differences have been found amongst different generations of monitors, thus despite some research on the earlier model RT3, it is likely that the RT6 differs in its ability to detect activity intensities (Rothney et al., 2008a,b). Of further concern are the predictive equations that are used to estimate physical activity which vary across software tools and are proprietary. Validation of the RT3 model and its estimates of energy expenditure suggest it underestimates energy expenditure during daily living activities (Lyden, Kozey, Staudenmeyer & Freedson, 2011). This has yet to be examined in the RT6 model and given that the monitor is able to display information (e.g. calories) to the wearer, this may provide a useful tool for understanding energy expenditure for practitioners and wearers without the need of complicated raw analysis.

Few studies to date have determined the validity and reliability of the RT6. Of the studies that have examined the performance of the RT6, significant differences between left and right hip position have been identified in older adults, (65+ years) (Sumukadas, Laidlaw & Witham, 2008). Additionally, when validity has been assessed, the focus has been on examining daily activities, with little consideration for sedentary behaviour, an area still under researched (Sanders et al., 2016). Given that young adults physical activity patterns differ from other population groups and that a transition to increasing sedentary patterns in seen from adolescence (Office of Disease Prevention and Health Promotion, 2010; McVeigh et al., 2016;Telama et al., 2015), a validation which is considerate to assessing all intensities of activity relative to common activities undertaking in these populations, is of importance.

To the author's knowledge, the only study (Duruturk et al., 2017) that has assessed the validity of the RT6 in adults did so using a protocol which limits generalisability to the range of physical activities undertaken in daily life as, in the case of Duruturk et al. (2017) they examined RT6 counts against pedometer determined step counts at different walking speeds. Given that pedometers are unable to provide information about intensity, frequency and durations and that accelerometers are the most reliable and popular method of assessing physical activity (PA) (Troiano et al., 2014), it seemed feasible to examine if the RT6 could compare as well as these competitive devices whilst also assessing energy expenditure comparative of the RT6 with gas. Other accelerometers models do not provide estimations of energy expenditure in their raw data or software and thus the translation of these values to energy expenditure equivalents is reliant on regression equations published within scientific literature. Given this device (RT6) is more user friendly, conveniently worn at the waist and the monitors are cheaper (approximately $200 per unit with freely available post processing software, compared to $300 for the Actigraph excluding post processing software which has an additional cost), if valid this may propose an attractive option for researchers and practitioners. Additionally, no cut points exist for the RT6 and how well these cut points represent habitual physical activity is based on the variety of activities that are included when validating monitors, which is yet to be established. The process of, and activities used in accelerometer calibration also has a meaningful influence on the precision of the accelerometers and prediction equations where accelerometers more easily classify ambulatory based activities (Ryan & Gormley, 2013). Therefore, calibration studies which provide a more holistic approach to measuring physical activity may provide further insight.

Of further interest is the placement and body positioning, as these factors are said to influence the accuracy in determining activity (Ellis et al., 2016; Hildebrand et al., 2014; Stec et al., 2012; Welk et al., 2000). Despite the usability of wrist worn devices, waist or hip worn devices are considered to be advantageous for gait, locomotor based activities, and for determination of energy expenditure, as they are more accurate (Murphy et al., 2009). The location (e.g. wrist, hip) and placement of monitors in terms of left or right side can not only impact on wear compliance but also the precision in equations for estimating physical activity (Crouter et al., 2018). Consequently, activity counts for determining the intensity of the activity differ depending on the monitor placement (Ellis et al., 2016), yet validation studies rarely include a range of positions and placements and this has not been examined in young adults nor with the RT6 monitor.

It is important to identify activity intensities in young adults to enable researchers to understand the link between activity guidelines and health outcomes, as well as understanding activity patterns in this population. Given the lack of data documenting the validity/utility of the RT6 monitors, the placement and cut points in young adults to determine activity intensity and across a range of laboratory and field based activities, this study sought to address this gap in young adults (18-30 years) with four aims: 1) To examine criterion validity of RT6 in comparison to breath by breath gas analysis; 2) To examine Convergent validity of RT6 in comparison to ActiGraph and GENEActiv; 3) To develop RT6 tri-axial vector magnitude cut points to classify physical activity at different intensities (i.e. for sedentary, moderate and vigorous); 4) To compare the generated cut-points of the RT6 in comparison to other tools. In doing this our work seeks to establishing validity of the RT6 in a younger adult sample, providing novel comparisons based on a range of lab based activities representing free living activity, location and including energy expenditure calculations.

MATERIAL AND METHODS

Participants

An opportunistic sample of 31, young healthy adults (22 males, 9 females, 97% right hand dominant) aged between 18 and 30 years (mean age ± SD = 22 ± 3) from central England took part in the study following approval from Coventry University Ethics Committee. Mean and ± SD of height, mass and body mass index (BMI) was 170 ± 9cm, 71 ± 11kg and 23 ± 3kg/m^2 respectively. A priori power calculation indicated that for a median effect at P=0.05 and 80% power would need a sample size of 27 (G*power software, 3.1.9.2, Franz Faul, Universitat Kiel, Dusseldorf, Germany).

Procedures

Calibration Protocol

The MetaMax 3B (Cortex Biophysilk GmbH, Leipzig, Germany) was set up and calibrated in accordance with the manufactures instructions. Throughout the validation protocol VO_2 and VCO_2 were assessed using a MetaMax 3B breath-by-breath gas analyser. The MetaMax 3B is found to be reliable and stable for the measurement of O_2 uptake (Meyer et al., 2001). Meyer et al., (2001) reported concurrent validity against another breath by breath system during incremental ramp exercise in young adults. Reliability (ICC = 1.00) are reported and technical error of measurement is reported as 0.2, 1.4 and 1.1% for VE, VO_2, VCO_2 when validated against an automatic gas exchange validator (Macfarlane & Wong, 2012). Overtime the MetaMax 3B has shown some drift in VO_2 and VCO_2 values when compared to the douglas bag method during simulated intermittent exercise lasting 180 minutes but all values were found to be below 2%, with the authors concluding that the drift in values is unlikely to be of physiological importance and thus the MetaMax 3B can be considered very stable (Macfarlane & Wong, 2012).

Using a USB connection to a computer with monitor specific software, all monitors, were time synchronized with the GMT server. The RT6 device settings were set to record using Kcal mode at a sampling rate of 10Hz, SMTL (1 sec), AFS set ± 4G, Gyroscope disabled, ActiGraph was set to record at (80Hz) using Actilife 6 (V6.13.2). GENEActiv V2.2 (ActivInsights Ltd) was set to record at 80Hz.

Validation protocol

All participants undertook five modes (i.e. supine rest, stepping, seated gaming, exergaming, treadmill walking and running, in the order listed) of physical activity/sedentary behaviour whilst wearing three different activity monitors at the same time that expired gas was sampled via breath by breath analysis.

Participants wore two RT6 (Stayhealthy Research Tracker, Stayhealthy Inc) monitors, one on their dominant hip and one on their non-dominant hip, close to the center of mass (posterior to the ActiGraph). In total, four ActiGraphs (GT9X Link, ActiGraph LLC) were worn. Monitors were placed at the anterior superior iliac spine (ASIS) of both hips and one at each wrist. A GENEActiv (ActiveInsights, Cambridge, UK) was placed distal to the ActiGraph at the wrist for both sides. All testing took place in the morning (9am-12noon) to avoid any potential differences due to circadian variation.

After briefing and fitting activity monitors and the gas analyser, each participant performed a series of activities to reflect different levels of physical activity, in the order listed below. These included lying supine, stepping (25cm height, 110bpm cadence as is indicative of stair climbing (Mair et al., 2016)), seated gaming (Xbox 360 – FIFA World Cup 2014), exergaming (Kinect dance – 2 dances including 50 cent ‘in da club’ and Katy Perry ‘Firework’), and exercised at 4 treadmill speeds (speed 3, 6, 9, 12 $km.h^{-1}$) (Woodway Inc, Wisconsin, USA). All activities were performed for 5 minutes with a wash out period of 5 minutes recovery in between (except stepping where the rest period was 10 minutes and treadmill walking/running as it was incremental for a purpose), these recovery times are congruent with previous published research (Duncan, Wilsom, Tallis & Eyre, 2016; Phillips, Parfitt & Towlands, 2014; Sasaki, John & Freedson, 2011). During the recovery period continuous breath by breath measurements were used to ensure gas exchange values were back to rest values before undertaking the next activities.

Data processing

Upon completion of the protocol, each participant's accelerometer and calorimetry data were downloaded and stored on a computer. RT6 files were extracted and exported as a CSV file using Research Tracker 6 (V3.1, Stayhealthy™). ActiGraph files were downloaded and exported as CSV files using Actilife 6 (V6.13.2), into 1-minute epochs. GENEActiv V2.2 (ActivInsights Ltd) were downloaded and summarised into 1-minute epochs to align the accelerometer and oxygen consumption data. Following alignment, the vector magnitude data were integrated into 1-minute intervals. Data were analysed as 1 minute epochs for various reasons. Firstly, the physical activity guidelines are recommended as minutes spent and thus in doing so it sought to be comparable/translatable to these guidelines. Secondly, data derived from oxygen and determined as MET is calculated in same time frames. Thirdly, research has shown that differences in bout durations of moderate to vigorous activity is beneficial to health regardless of how the bout durations are made up (Jefferis et al., 2016). Finally, 1 minute epoch length is the most commonly reported in validation studies in adults and Migueles et al., (2017) review reported that there was no information about the influence of epoch length for adults.

Data Analysis

The first and last minute of each bout was discarded leaving a 3 minute period for analysis, consistent with previous work (Duncan, Wilson, Tallis & Eyre, 2016).

The raw data for each device (RT6, GENEActiv and ActiGraph) were individually summed into a signal magnitude vector per device, expressed in 60 second epochs as is conventional (Duncan, Wilson, Tallis & Eyre, 2016; Phillips, Parfitt & Towlands, 2014; Plasqui, Westerterp, 2007; Sasaki, John & Freedson, 2011). Total calories from the raw RT6 output was also summed over the 3 minute period.

Average VO_2 was determined over the same 3 minute period. VO_2 data were then further converted to METs using the resting VO_2 for the individual. These MET values were then coded into one of the four intensity categories (e.g. sedentary, light, moderate or vigorous), according to those most commonly applied (Hills, Mokhtar & Byrne, 2014, WHO, 2010). Energy expenditure was determined using the MetaMax 3B, which uses a respiratory quotient based equation with an assumed protein utilization part of total energy production (15%) according to Acheson (1988). Accelerometer data were then recoded to create a binary indicator variable (0 or 1) to facilitate Receiver Operating Characteristic Curves (ROC) analysis. This is similar to previously published research examining validity of physical activity monitor tools and determining cut points for classifying physical activity (Esliger et al., 2011; Evenson et al., 2008).

Statistical Analysis

Normality tests were conducted using Kolmogorov and Shapiro-Wilk and identified that variables were not normally distributed ($P<0.05$). Spearman's product moment correlations were performed to assess criterion and convergent validity between RT6 devices accelerometer counts.min^{-1} (vector magnitude) compared to METs, VO_2 (l.min^{-1}) and activity devices (ActiGraph and GENEActiv) accelerometer counts.min (vector magnitude) as well as energy expenditure from breath by breath analysis compared to that derived from the RT6. Agreement was examined using Bland Altman plots whereby the RT6 monitor worn on the right side was compared to the RT6 monitor worn on the left side. Furthermore, energy expenditure determined from gas and the RT6 monitor were compared. These were performed in GraphPad Prism (v6, GraphPad Software Inc, California, USA)

Receiver operating characteristic curves (ROC) and analysis were used to calculate area under the curve (AUC), sensitivity and specificity as described by Esliger et al., (2011). Accelerometer counts were used as the test variables and the MET levels obtained from the VO_2 ($l.min^{-1}$) was binary coded as the state variable. In this way we sought to compare how well each accelerometer could classify the intensity of activities compared to that of breath by breath analysis. Using the data collected, calculation of appropriate cut points were performed in excel for sedentary (≤1.5 METs, Tremblay et al., 2017) light (>1.5 to <3 METs), moderate (3-5.99 METs) and vigorous (≥6 METs, Hills, Mokhtar & Byrne, 2014; Migueles et al., 2017; WHO, 2010) based on a 60 sec epoch length and location of measurement with optimal levels of sensitivity and specificity. In line with previous accelerometer calibration studies, the aim of ROC analysis is to identify the cut point that maximises both sensitivity and specificity. The ROC-curve coordinates, and sensitivity and specificity values were used to find the maximal sensitivity and specificity (Youden-index = maximum (sensitivity + sensitivity -1) of the corresponding ROC curves giving cut point values. An AUC of 1 represents perfect classification, values ≥0.90 are considered excellent, 0.80-0.89 good, 0.70-0.79 fair, and <0.70 poor (Metz, 1978). In line with prior work, AUC was determined for sedentary, moderate and vigorous activity, leaving accelerometer counts that fell between the sedentary and moderate activity cut-points were then classified as light PA, in line with prior work (Phillips, et al., 2014).

Cut-points for light physical activity were classed as those higher than sedentary but lower than moderate physical activity but did not require AUC, Sensitivity or Specificity values to be determined as per Phillips, et al. (2014). These are subsequently labelled as not applicable (NA) in Table 3.

Using the new cut points which were generated from ROC, the counts.min^{-1} for each monitor were recoded into a dichotomous variable (1 or 0) depending of the intensity. Cohen’s Kappa agreement (K) was used to compare the determination of activity intensity based on the cut points for the RT6 monitors compared with METs from gas and other monitor tools, investigating the sensitivity, specificity and measure of agreement. The agreements can be interpreted using the following scale: .00-.20 slight agreement, .21-.40 fair agreement, .41-.60 moderate agreement, .61-.80 substantial agreement and .81-1.00 almost perfect agreement (Viera & Garrett, 2005).

RESULTS

Descriptive data for RT6 and METs for each exercise condition can be found in Table 1.

Criterion and Convergent Validation

Using Spearman’s correlations, the RT6 (VM accelerometers counts.min^{-1}) yielded a moderate significant positive association with METs (r= 0.77 to 0.817), VO_2 (l.min^{-1}) (r=0.786 to 0.814), GENEActiv and ActiGraph monitors regardless of location (Table 2). Of all the devices, the RT6 dominant hip yielded the strongest associations with METs or VO_2 (l.min^{-1}), performing better than comparative ActiGraph or GENEActiv devices (Table 2). The total calories calculated using RT6 also revealed significant moderate associations with energy expenditure derived from breath by breath analysis (r=0.702 to 0.756, P<.01) and VO_2 (l.min^{-1}) (r=0.777 to 0.838, P<.01), observing stronger associations when the monitor was placed on the participants dominant side. Of all the tools, the ActiGraph hip worn devices yielded the strongest associations with MET_S and VO_2 (l.min $^{-1}$), followed by RT6, wrist worn ActiGraph devices and GENEActiv wrist worn. RT6 devices were also found to have the strongest positive associated with ActiGraph hip worn devices (r= 0.929 to 0.960, P<.01). In addition, bland altman plots identified a small risk of bias (bias = - 4 counts.min^{-1}, SD of bias = 38 counts.min^{-1}, 95% LOA = -77 to 69 counts.min^{-1}) between dominant and non-dominant positioned RT6 monitor (Figure A).

Significant moderate associations were found between energy expenditure determined from the RT6 dominant and non-dominant with energy expenditure from gas (r=0.70 – 0.76). Furthermore, when energy expenditure derived from the RT6 was compared with gas, the trends indicate good agreement in sedentary and low intensity but agreement is poorer at higher intensity activities as illustrated in Figure B (bias = -1.6 Kcal.min^{-1}, SD of bias = 7.9 Kcal.min^{-1}, 95% LOA = --13.8 to 17.18 Kcal.min$^{-1)}$ & C (bias = -1.0 Kcal.min^{-1}, SD of bias = 7.3 Kcal.min^{-1}, 95% LOA = -13.2 to 15.3 Kcal.min^{-1}).

AUC, sensitivity and specificity of RT6 cut points.

When compared to METs, the RT6 yielded good to excellent classifications for sedentary (AUC = 0.862, 0.911), moderate (AUC = 0.849, 0.830) and vigorous intensity activity (AUC = 0.849, 0.830, Table 3). Similar classifications were found for other activity monitoring devices and locations (Table 3). Generally, monitors performed better when they were placed on the dominant side. The RT6 and

ActiGraph hip worm devices performed similar to each other with wrist worn devices yielding poorer classifications for moderate intensity activity (Table 3).

Determination of RT6 tri-axial cut points across physical activity intensities

ROC analysis was used to generate cut points for different activities intensities. The cut points yielding the highest value of sensitivity and specificity can be found in Table 3. When the RT6 monitor is positioned on the non-dominant side, the cut points are as follows; Sedentary ≤18 counts.min^{-1}, Moderate ≥113 counts.min^{-1} and Vigorous ≥452 counts.min^{-1}. For the dominant side, the cut points are as follows; Sedentary ≤19 counts.min^{-1}, Moderate ≥139 counts.min^{-1} and Vigorous ≥488 counts.min^{-1} (Table 3).

Comparison of generated cut points

A summary of the agreement with corresponding sensitivity and specificity values between METs from gas, ActiGraph, GENEActiv monitors against the RT6 monitor placed on non-dominant and dominant side, can be found in Table 4. In the determination of sedentary, light and moderate activity, the RT6 monitor showed the best agreement with ActiGraph monitors worn at the hip. However, for Vigorous exercise, stronger agreement was found with the GENEActiv wrist worn devices. A more detailed breakdown of these comparisons can be found below.

Sedentary behaviour classification

Comparison of all the new cut points for activity of sedentary intensity yielded strong agreement between the RT6 devices and other monitoring tools (Table 4). Almost perfect agreement was found for dominant and non-dominant ActiGraph hip worn devices (K range = 0.84-0.97, Table 4) and GENEActiv wrist worn devices (K range = 0.84 – 0.95) with RT6 placed in both positions. Almost perfect agreement was also found for ActiGraph non-dominant and dominant placed wrist worn devices with RT6 dominant hip placed (K = .860) and substantial agreement was found for ActiGraph non-dominant and dominant placed wrist worn devices with RT6 non-dominant hip placed (K = .75). The agreement between gas determined as METs and RT6 dominant hip placed monitor yielded substantial agreement (K = .72) but only moderate with non-dominant placed hip monitor. Across all comparisons with the RT6, the sensitivity and specificity was better when the device type was compared with the RT6 monitor placed on the dominant side.

Light physical activity classification

Almost perfect agreement was shown between the RT6 monitors with the ActiGraph devices placed on the hip location (K Range = 0.85 – 0.97) with the strongest agreement against the RT6 positioned on the dominant hip (K range = 0.96- 0.97). Moderate agreement was shown when the GENEActiv monitors and METs were compared with the RT6 devices (K range = 0.43- 0.56), with fair agreement apparent when between the ActiGraph wrist worn devices with the RT6.

Moderate physical activity Classification

Substantial agreement was found between the ActiGraph hip worn devices and RT6. The RT6 devices showed moderate agreement with GENEActiv wrist worn devices and fair with ActiGraph wrist worn and METs from gas (Table 4).

Vigorous physical activity classification

The RT6 performed almost perfect against GENEActiv wrist worn devices (K range = 0.85- 0.89), substantially with ActiGraph wrist worn (K range = 0.73- 0.79) and moderate with gas (K range = 0.57-0.59) and ActiGraph hip worn devices (K range = 0.49-0.55).

DISCUSSION

This is the first study to identify criterion and convergent validity between RT6 with GENEActiv, ActiGraph and gas analysis in young adults. In addition, this study identifies cut points for activity intensities derived from a range of movements reflective of different types of physical activity in young adults. This is supportive of Esliger et al (2011)'s work, establishing the validity between GENEActiv and ActiGraph with the older model of the RT6 (RT3) in older adults. Our work extends upon this aforementioned work by establishing validity of the RT6, worn in different locations, in a younger adult sample and providing novel comparisons based on a range of lab based activities representing free living activity. The findings of this current study raise concerns for the accuracy of the RT6 in determining the presence of vigorous activity and energy expenditure estimates during activities at higher intensity. Irrespective of intensity, hip based devices performed the best and these placed on the dominant hip yielded the best agreement. These findings support previous literature which has compared hip versus wrist worn devices and have shown that hip based devices have higher accuracy and larger explained variances in classify activity type and intensity (Ellis et al., 2016; Hildebrand et al., 2014; Stec et al., 2012). However, our findings also identify that this may not be the same for all types of activities, as wrist worn devices performed better for vigorous activity. This was surprising given that the exercises which were of a vigorous intensity were stepping and running (12 $km.h^{-1}$), which are considered to be locomotor in nature and hip worn devices are better at predicting locomotor activities (Ellis et al., 2016). Given that the physical activity guidelines for adults include guidelines around vigorous exercise, and that high intensity exercise is considered to have health benefits (Gillen & Gibala, 2013), accurate identification of vigorous exercise is important. Our findings suggest that wrist worn devices provide better accuracy at these intensities, but if interested in other intensities i.e. sedentary, moderate, hip worn devices are better, thus using a combination of these tools may provide more accurate identification.

When compared to METs, the RT6 performed slightly better at the dominant hip than the non-dominant hip. This suggests that the newer RT6 device may still have similar measurement issues as its predecessor (RT3), where significant differences were found between hip positions in older adults (65+) (Sumukadas, Laidlaw & Witham, 2008). As a consequence, very subtle differences in the cut points generated by position and side dominance were found. However, it is important to notice that this bias was very small (4 counts,min^{-1}), which may be reflective of movement that is not always symmetrical in the body due to differences in skeletal muscles generating the movement at the location. The findings of the present study extend prior work by Sumukadas, Laidlaw and Witham (2008) by examining whether there was a difference in RT6 values if positioned on the dominant or non-dominant hip. Our findings suggested that hip worn devices are better at identifying activity intensity when worn on the dominant compared to non-dominant hip. This supports prior assertions that cut-points should be determined relative to position and side dominance (Esliger et al., 2011), instead of using universal cut points which do not consider whether hip worn accelerometers are positioned on the dominant or non-dominant hip. As this is one of the first studies to identify cut points for RT6, there is limited data available to make comparisons. However, vector magnitude data collected in young adults during brisk walking speeds has been found to be between 155 to 369 counts.min^{-1} (Duruturk et al., 2017), which is in line with the cut points generated for moderate intensity in this study (>113 and 136 counts.min^{-1} respectively). Further cross validation of these cut points is now needed. In addition, the cut points generated for hip worn ActiGraph monitor are also comparable to those derived for the GTX3 in Sasaki et al., (2011) for moderate activity. Yet, the values in this study are much higher than those in Sasaki et al., (2011). Our protocol was similar to Sasaki et al., (2011) in which we used treadmill running at 12 km.h^{-1}, however our study further included stepping which was the equivalent of stair climbing and at vigorous intensity. Given that many participants in the present study could not finish exercising at 12 km.h^{-1}, and that a rest period was not implemented between each running activity, it is likely that this influenced the vigorous intensity cut points. However, the MET values obtained during the different treadmill speeds are consistent (i.e. Light <4km.h^{-1}, moderate 4-7.2km.h^{-1} and vigorous >7.2km.h^{-1}) with the expected values identified in previous work (Ainsworth et al., 2000). Future research may seek to randomise the order of these activities and to provide a longer wash out period to examine this further.

Of all the devices, the ActiGraph hip worn devices performed the best when compared to MET_S, VO_2 and of interest the RT6 yielded the strongest associations and agreement with the ActiGraph, which suggests it provides a comparable tool. This is of importance to researchers, clinicians, health care practitioners as the information on the RT6 device can be viewed by the wearer unlike the ActiGraph, the monitor is cheaper and the software is user friendly. Of further interest is the energy expenditure estimates which may provide useful in the application of energy balance. The energy expenditure estimations from the RT6 were found to be moderatelyassociated and demonstrated agreement, however the predictions across activity intensities shows some systematic bias.

Limitations:

The strengths of the work involve the use of ROC curves to determine cut points across devices. The study has enabled the development of these cut points across a full range of activity intensities (e.g. sedentary to vigorous) based on a range of lab based activities representing free living activities, using individualised METs for a young adult population. Cross validation is now needed to establish the generalisability of the established cut points to other populations. Additionally, the work sought to include activities of daily living such as exergaming and stepping, as a proxy for stair climbing. However, the activities chosen may not fully represent the range of physical activities undertaken by young adults. In childhood validation studies, machine learning approaches are being implemented. This more advanced analysis in future work may help to develop monitoring and measurement of physical activity in free living environments. Of further interest, the RT6 provides a kinematic mode, the validity of which has not been explored.

Furthermore, a larger proportion of males were recruited to the study and thus further research may need to evaluate the role of sex, body size/stature and its biomechanical impact on physical activity estimates. Given the nature of the tri-axial accelerometers and the software available to determine more complex assessment of physical activity such as kinematic mode, further research may examine this. The current activity cut points are based on the vector magnitude count and thus the study sought to use these values to enable comparison across studies and devices, as well as providing an easy and effective way to determine physical activity for practitioners with limited time to perform additional calculations. The study sample for vigorous activity was lower, due to four participants being unable to complete the 5 minutes running at speed 12 $km.h^{-1}$. Despite this, the AUC was good across the devices. In future, a longer wash out period and a randomised order of testing needs to be explored. While standardised procedures were enforced, the bias of two monitors positioned on the same joint was not assessed in this study and may have impacted on the accuracy of derived activity counts and cut points for wrist worn devices. However, the impact of this is expected to be minimal based on prior research using the ActiGraph GTX that has indicated high reliability between devices at the same location, concluding that any subtle differences in placement seen at the same joint would not have a meaningful impact on the intensity classifications (Ozemek et al., 2014). Another factor to consider is the role of the individuals fitness level on the classification of the intensity, while individualised MET values were used based on resting oxygen consumption values, the generalizability of the cut points derived for activity may not apply across all adult populations. This is because varying oxygen consumption levels occur when individuals exercise at the same intensity (Whitcher & Papadopoulos, 2014). While the individuals in this study were deemed as healthy based on completing a health screen identifying they engage in regular physical activity, their specific fitness level was not assessed. Finally, the sampling rate for the RT6 was lower (10Hz) when compared with ActiGraph and GENEActiv, this was because this is the only option available for the RT6 when using Kcal mode.

CONCLUSION:

The RT6 is a valid and comparable tool to breath by breath gas analysis, GENEActiv and ActiGraph for assessing sedentary, moderate and vigorous activity intensities. In young adults, hip based devices were superior in determining intensity of activity, with the ActiGraph hip worn device performing the best in comparison to other tools and in comparison to the RT6. However, the RT6 offers a comparable alternative tool for clinicians/practitioners with the inclusion of energy expenditure which can be visually viewed during wear, making a more user friendly and feasible tool for understanding current PA levels and in intervention studies to monitor and track changes without the excessive need for downloading and making complex analysis. Further research should seek to further cross validate the cut points generated across adult populations of varying fitness levels and to explore the kinematics mode available in the monitor.

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Table 1. Mean ± SD for activity counts, VO_2 and energy expenditure across different exercise conditions.

Measure/place	Units	Supine Rest	Stepping	Seated Gaming	Exergaming Dance 1	Exergaming Dance 2	Treadmill Speed 3 $km.h^{-1}$	Treadmill Speed 6 $km.h^{-1}$	Treadmill Speed 9 $km.h^{-1}$	Treadmill Speed 12 $km.h^{-1}$
Expired Breath										
VO_2	$l.min^{-1}$	0.38 ± 0.12	2.06 ± 0.69	0.41 ± 0.11	0.79 ± 0.08	0.87 ± 0.32	0.65 ± 0.17	1.01 ± 0.25	1.87 ± 0.59	2.36 ± 0.82
Energy Expenditure	METs	NA	5.5 ± 1.8	1.37± 0.67	2.12 ± 0.64	2.3 ± 0.73	1.7 ± 0.4	2.7 ± 0.7	4.9 ± 1.5	7.2 ± 1.8
	$Kcal.min^{-1}$	1.9 ± 0.6	27.1 ± 8.8	3.8 ± 5.0	3.8 ± 1.12	4.3 ± 1.6	3.25 ± 0.9	4.9 ± 1.3	10.2 ± 5.3	11.8 ± 4.2
RT6 - Hip										
Non-dominant	$Counts.min^{-1}$	0 ± 0	136 ± 61	0.12 ± 0.42	82 ± 43	91 ± 42	95 ± 55	204 ± 68	447 ± 152	544 ± 197
Dominant	$Counts.min^{-1}$	0 ± 0	152 ± 39	3 ± 11	92 ± 44	100 ± 44	94 ± 47	230 ± 103	471 ± 101	574 ± 128
Non-dominant	$Kcal.min^{-1}$	1.2 ± 0.5	4.9 ± 1.8	1.3 ± 0.3	3.4 ± 0.7	3.6 ± 0.8	3.7 ± 0.5	7.0 ± 1.7	14.2 ± 4.2	15.9 ± 4.5
Dominant	$Kcal.min^{-1}$	1.4 ± 0.2	5.6 ± 1.3	1.3 ± 0.7	3.4 ± 0.7	3.8 ± 1.1	3.9 ± 0.9	7.0 ± 1.3	14.4 ± 3.0	17.5 ± 3.6

Table 2: Correlation Matrix between monitor (counts.min^{-1}), METs and V0$_2$ (l.min^{-1}).

	METs	VO$_2$	RT6 Non-Dominant Hip	RT6 Dominant Hip	GENEActiv Non-Dominant	GENEActiv Dominant	ActiGraph Non-dominant Wrist	ActiGraph Dominant wrist	ActiGraph Non-dominant Hip	ActiGraph Dominant hip
RT6 Non-Dominant Hip	0.765**	0.786**								
RT6 Dominant Hip	0.817**	0.814**	0.956**							
GENEActiv Non-Dominant Wrist	0.680**	0.718**	0.811**	0.839**						
GENEActiv Dominant Wrist	0.692**	0.722**	0.792**	0.836**	0.976**					
ActiGraph Non -Dominant Wrist	0.750**	0.723**	0.792**	0.791**	0.892**	0.892**				

ActiGraph Dominant Wrist	0.788**	0.751**	0.811**	0.805**	0.948**	0.948**	0.960**		
ActiGraph Non-Dominant Hip	0.876**	0.835**	0.938**	0.929**	0.860**	0.860**	0.771**	0.862**	
ActiGraph Dominant Hip	0.900**	0.871**	0.960**	0.939**	0.852**	0.852**	0.777**	0.856**	0.972**

Table 3: Areas under the ROC curve and cut points that maximise sensitivity and specificity

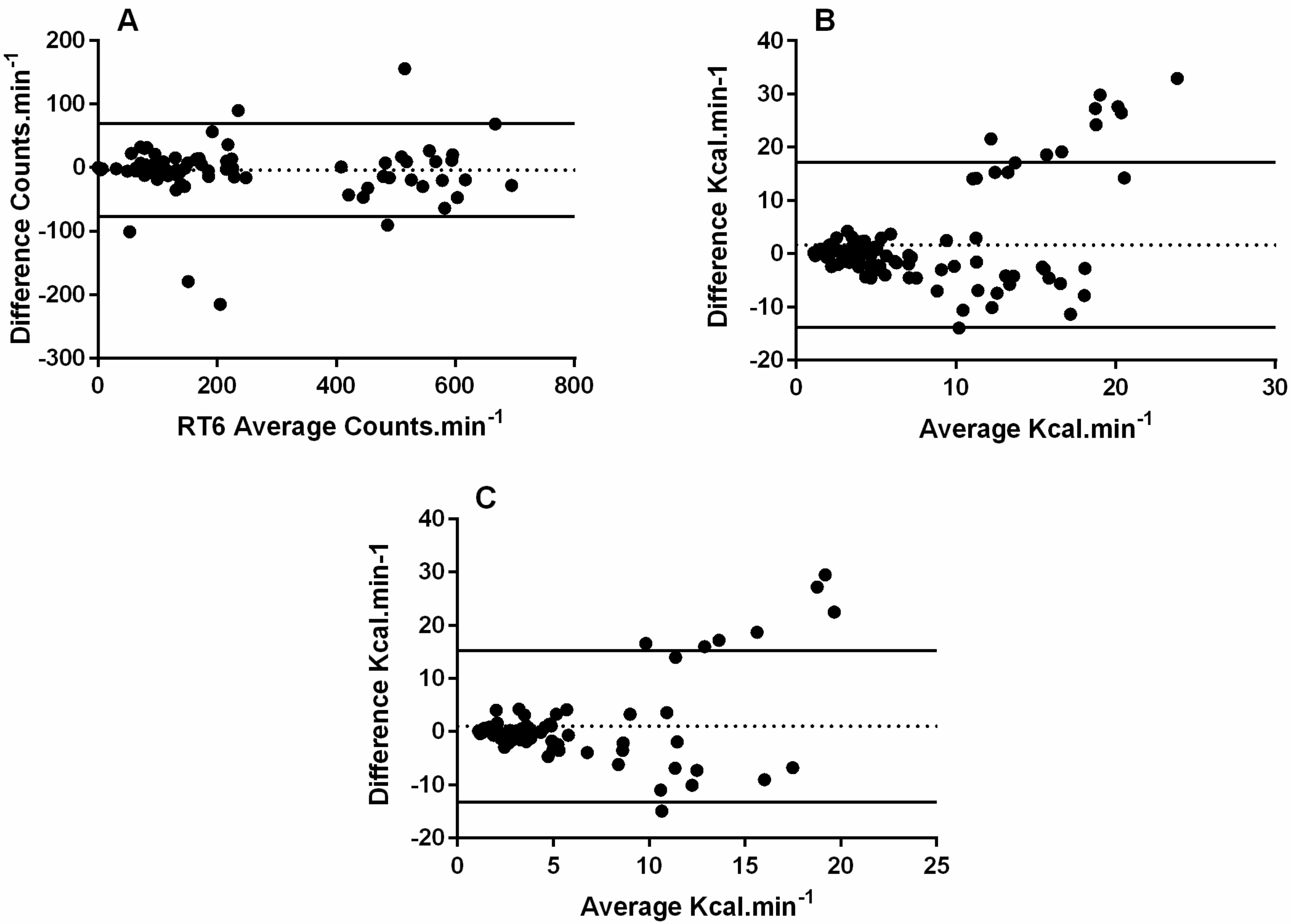
Activity Monitor	Location	AUC	Cut point VM Counts.min^{-1}	Sensitivity	Specificity
SEDENTARY					
RT6	Non-dominant HIP	0.862	≤18	0.886	0.765
	Dominant HIP	0.911	≤19	0.896	0.851
GENEActiv	Non-dominant wrist	0.827	≤503	0.865	0.783
	Dominant wrist	0.828	≤464	0.865	0.783
ActiGraph	Non-dominant wrist	0.935	≤2635	0.845	0.946
	Dominant wrist	0.942	≤1741	0.879	0.941
	Non-dominant HIP	0.942	≤526	0.879	0.946
	Dominant HIP	0.947	≤553	0.888	0.946
LIGHT	not applicable as cut points are derived as values between sedentary and moderate				
MODERATE					
RT6	Non-dominant HIP	0.849	≥113	0.952	0.707
	Dominant HIP	0.830	≥139	0.938	0.743
GENEActiv	Non-dominant wrist	0.741	≥1268	1.000	0.557
	Dominant wrist	0.776	≥1266	1.000	0.575
ActiGraph	Non-dominant wrist	0.738	≥4187	0.933	0.512
	Dominant wrist	0.755	≥5901	0.929	0.575
	Non-dominant HIP	0.851	≥3823	0.933	0.756
	Dominant HIP	0.849	≥2876	1.000	0.691
VIGOROUS					
RT6.	Non-dominant HIP	0.872	≥452	0.818	0.765
	Dominant HIP	0.877	≥488	1.00	0.616
GENEActiv	Non-dominant wrist	0.870	≥5120	0.750	0.930
	Dominant wrist	0.873	≥5015	0.750	0.915

ActiGraph	Non-dominant wrist	0.790	≥20355	0.950	0.579
	Dominant wrist	0.848	≥19858	0.944	0.504
	Non-dominant HIP	0.889	≥10517	0.950	0.805
	Dominant HIP	0.928	≥10482	0.950	0.857

Table 4. Comparison of RT6 cut points and their respective Specificity, sensitivity based on cut points derived from ROC in with METs, GENEActiv and ActiGraph monitors.

			RT6 Non-dominant hip			RT6 Dominant hip		
Comparison device	**Location**	**Intensity**	**Sensitivity**	**Specificity**	**Kappa (k)**	**Sensitivity**	**Specificity**	**Kappa (k)**
METs from gas	NA	Sedentary	.75	.93	.63**	.94	.75	.72**
ActiGraph	Non-dominant hip	Sedentary	.89	.95	.85**	.95	1.00	.96**
	Dominant hip	Sedentary	.91	.95	.86**	.96	1.00	.97**
	Non-dominant wrist	Sedentary	.80	.93	.75**	.85	.98	.86**
	Dominant wrist	Sedentary	.78	.93	.75**	.83	1.00	.86**
GENEActiv	Non-dominant wrist	Sedentary	.88	.96	.85**	.93	1.00	.95**
	Dominant wrist	Sedentary	.86	.96	.84**	.91	1.00	.93**
METs from gas	NA	Light	.56	.95	.54**	.61	.93	.56**
ActiGraph	Non-dominant hip	Light	.84	.98	.85**	.98	.99	.97**
	Dominant hip	Light	.85	.98	.86**	.96	.99	.96**
	Non-dominant wrist	Light	.50	.78	.19**	.50	.75	.16*
	Dominant wrist	light	.57	.79	.26**	.57	.76	.20**

GENEActiv	Non dominant wrist	Light	.95	.83	.50**	.95	.80	.45**
	Dominant wrist	Light	.95	.83	.50**	.91	.80	.43**
METs from gas	NA	Moderate	.56	.80	.30**	.56	.84	.36**
ActiGraph	Non-dominant hip	Moderate	.64	.92	.60**	.64	.98	.67**
	Dominant hip	Moderate	.67	.93	.63**	.67	.98	.70**
	Non-dominant wrist	Moderate	.49	.89	.39**	.42	.90	.34**
	Dominant wrist	Moderate	.52	.87	.41**	.45	.89	.37**
GENEActiv	Non dominant wrist	Moderate	.60	.96	.60**	.53	.97	.54**
	Dominant wrist	Moderate	.60	.95	.58**	.53	.96	.53**
METs from gas	NA	Vigorous	.67	.91	.59**	.70	.91	.57**
ActiGraph	Non-dominant hip	Vigorous	1.0	.88	.52**	1.0	.87	.49**
	Dominant hip	Vigorous	1.0	.89	.55**	1.0	.87	.52**
	Non-dominant wrist	Vigorous	.96	.94	.77**	.96	.92	.74**
	Dominant wrist	Vigorous	.81	.95	.73**	.87	.95	.79**
GENEActiv	Non dominant wrist	Vigorous	.90	.97	.85**	.97	.97	.89**
	Dominant wrist	Vigorous	.93	.97	.87**	.97	.96	.87**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****** insert Figure A ******

Figure A RT6 dominant versus RT6 non dominant (Vector Magnitude counts.min^{-1})

****** insert figure B here ******

Figure B Kcal.min^{-1} determined from gas versus Kcal.min-^{1} determined from the RT6 dominant

****** Insert Figure C here ******

Figure C Kcal.min^{-1} determined from gas versus Kcal.min-^{1} determined from the RT6 non-dominant

Acknowledgements

We would like to thank Ines Branco for her help in some of the data collection involved in this study

Authors Contributions

EE lead the study and was involved in designing the study, data collection, statistical analysis and drafted the manuscript. **MD** was involved in the design of the study, statistical analysis and provided guidance on the drafted manuscript. **JT** was involved in designing the study, data collection and drafting the manuscript. **SW, LA, LW, RW** were involved in data collection and data analysis of the raw data collected and contributed to drafting manuscript.

Competing Interest

None of the authors declare competing financial interests.

Funding sources

The work was not supported by any financial grant.